WHY A VARIABLE G?

(*Letter to the Editor*)

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Abstract. Since a possible time variability of G has received renewed attention (Wesson and Goodson, 1981), we think it is important to stress a conceptual aspect so far not sufficiently appreciated and which puts the variability of G in a much wider context. Variable G is a popular but incomplete representation of a much deeper problem: *Is the Strong Equivalence Principle (SEP) valid?*

In its simplest form, (Will, 1979) the SEP assumes that *gravitational clocks* (two orbiting planets) and *atomic clocks* (an hydrogen atom) are indistinguishable – i.e., that the switching from one clock to the other does not affect the results of any measurements. More precisely, the SEP implies that the two clocks are synchronous over *any* period of time, thus rendering them operationally indistinguishable.

A gravitational clock is governed by gravity alone and therefore is regarded as fully described by the best gravity theory known at present, the general theory of relativity, GR. *An atomic clock* is on the other hand governed by electric forces described by another superbly verified theory, quantum electrodynamics, QED.

The next step is to know how the two clocks relate to one another. Neither GR nor QED can be expected to answer the question, since they deal with the two phenomena separately. To know the answer, we must have *something more*, such as a unified theory of gravity and electromagnetism. Since unfortunately such theory is still unavailable, it follows that we do not have the answer to our question either, a state of affairs that has been mended by accepting the SEP, which proposes the following answer: the two clocks are identical.

Given the importance and implications of the SEP, it is relevant to inquire as to how well verified is this 'guessed at' solution.

The variability of G is a limited representation of the same question. In fact, since G is the 'spring', so to speak, of the gravitational clock, the possibility that the SEP may be violated, i.e. that the two clocks may run at different rates, can be equivalently expressed by saying that G varies with respect to atomic clocks.

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Since a non-constant ratio in time of the two clocks is a relative affair, we could equivalently have started by saying that atomic clocks are possibly not-constant with respect to the gravitational ones. However, since we always deal with atomic clocks in actual measurements, we make more frequent use of the G-variability point of view, an aspect which should however be viewed within the preceding framework.

A violation of the SEP implies the age of the universe as a time scale and therefore cannot be expected to be larger than $\sim 10^{-11}\ \mathrm{yr}^{-1}$. This may explain why it is so difficult to detect, if existent at all. This circumstance does not however allow us to conclude that the SEP holds true at all time scales. It might, but this has not yet been proven. In our point of view, the SEP has so far been a good substitute for the lack of a unified theory, but one which now should be scrutinized as closely as possible.

It is furthermore clear that the search for a violation of the SEP does not imply changes of Einstein equations and/or of Maxwell equations, which retain exactly their original form *provided* each theory is written in a system of units based on its own clock. Put differently, QED is unchanged so long as we use *atomic clocks*, and GR is unchanged so long as we employ *gravitational clocks*. The problem is to understand how they couple.

But how do we know that 'distortions' do not creep in when we study one phenomenon, say orbital motions, using the atomic clock governed by the other, so far an unrelated, dynamical theory? As we already said, it may well be that no 'distortions' occur. But being a fundamental question, we better *make sure* of it by directly confronting the SEP with the possibility that it might be violated.

The large wealth of data at our disposal from different fields has been used in the last few years in an attempt to answer precisely this question. The answer (Canuto and Goldman, 1982a, b), based on data from the time of nucleosynthesis until today, is that a violation of the SEP, *may exist*, *provided* it is not larger than a factor of ~ 30 in $G(t)$ vs G_0 (today). *This compatability verdict from the existing data is all we can expect from a theoretical analysis.*

The next step, a purely observational one, will confirm or deny whether such a possibility is indeed materialized. For this reason, in collaboration with Dr R. Hellings and P. J. Adams of JPL, we are at present reanalyzing the Viking data to Mars to study, in a model independent way, the influence of atomic clocks in recording purely gravitational phenomena.

Since these data are not hampered by tidal effects as in the case of the lunar data, they ought to provide by far the most reliable test of the variability of G and the validity of the SEP.

In conclusion, the study of the violation of the SEP (or the variability of G) is therefore *not* the study of some esoteric variation that is 'obviously' not there. On the contrary, it is an effort to check an *assumption*, the SEP, that might not be there.

References

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